

### Introduction

This poster shows the distribution of Quaternary-active faults in the San Francisco Bay region and explains what they are, why they are important, and how geologists study them.

Quaternary-active faults are those that have slipped in Quaternary time (the last 1.8 million years). Geologists think that these faults are the most likely source of future great earthquakes, so it is important to know what they are, where they are, and how they work.

The map at the center of this poster shows Quaternary-active faults as differently colored lines on a computer-generated image of the region. This image combines LANDSAT satellite photography, digital elevation data, and digital water-depth data.

This fault map is derived from the ongoing work of the Northern California Quaternary Fault Map Database Task, which is a group of geologists from the U.S. Geological Survey, California Geological Survey, and consulting firms. Their work is to make and compile a modern map database of Quaternary fault information. They are largely funded by the USGS National Earthquake Hazards Program.

### What makes a fault break?

Where the Earth's tectonic plates collide, pull apart, or slide by each other, they form and drive faults.

Although the Earth seems very stable on a human time scale, over geologic time it is a very dynamic system. Rock bodies are continuously being made and destroyed. Mountains are pushed up and ground down. Huge slabs of the Earth's surface are sliding and grinding past and over one another.

Fossilized fragments of a marine animal called *crinoid*, or sea lily (left), have been found near the top of Mount Everest (right), evidence of the dynamic forces that drive faults.

The powerful forces that drive this system cause huge slabs of the Earth's crust, called tectonic plates, to grind and push against one another. The rocks along the boundaries of these plates are continuously being squeezed and sheared, causing them to bend and break. California is cut by one such plate boundary, between the Pacific and North American plates, at the San Andreas Fault system. All the Quaternary-active faults in the San Francisco Bay region are part of the San Andreas Fault system.

### How do geologists find Quaternary-active faults?

Geologists trace faults by following the characteristic effects that young faults have on the landscape.

Some faults, called creeping faults, move very slowly all the time. Structures such as bridges, sidewalks, and buildings on top of these faults will be offset a small amount each year as the faults move. You can try to find a creeping fault by looking for bent or offset curbs and sidewalks. Not every offset curb is a fault, but if you find several offsets that line up, you may have found a creeping fault.

This curb in Hayward is being offset by creep on the Hayward Fault. Notice the change between 1974 and 1993.

### How do geologists find when a fault last broke?

Geologists find the age of prehistoric fault rupture where faults cut young deposits.

Although the evidence in the landscape that a fault leaves behind can guide geologists to Quaternary-active faults, it cannot tell them just when the fault last lurched in an earthquake. In the San Francisco Bay region, geologists have mapped the extent of ground rupture for only three earthquakes: 1868 (Hayward Fault), 1906 (San Andreas Fault), and 1980 (Greenville/Las Positas Faults). Everywhere else, they have to determine the age of the most recent fault rupture in other ways.

Earthquakes can offset and disrupt the sedimentary layers that naturally accumulate over time from deposition by rivers, streams, wind, and waves. If a layer is not cut or bent by a fault, then the last earthquake on that fault must have occurred before the layer was deposited.

### Learn more about it

Visit our website to see more maps, photos, diagrams, downloads, and information about Quaternary-active faults and other aspects of the geology of the San Francisco Bay region.

<http://sfgco.wr.usgs.gov>

### What is a fault?

A fault is a break in the rocks that make up the Earth's crust, along which rocks on either side have moved past each other.

Not every crack in the ground is a fault. What defines a fault is the movement of the rock on either side. When that movement is sudden, the released energy causes an earthquake.

Some faults are tiny, but others are part of great fault systems along which rocks have slid past each other for hundreds of miles. These fault systems are the boundaries of the huge plates that make up the Earth's crust. In the San Francisco Bay region, the Quaternary-active faults are part of the boundary between the Pacific and North American plates.

### What is the Quaternary?

Quaternary time is the current period of geologic time, which began about 1.8 million years ago.

We divide time into years, months, and days, and we give these divisions names, such as 1776, August, and Friday. Similarly, geologists have divided the time of Earth's long history into eons, eras, periods, and epochs of geologic time, and they have given each division a unique name. When they first started using these names, nobody knew how old the Earth was, or how many years ago the time divisions were. Instead, they based the division of time on how the fossils found in rocks changed from the oldest layers to the youngest. The Quaternary period is the name for the time in which we live. It spans the two most recent geologic epochs, the Pleistocene and the Holocene. Fossils from the Holocene epoch are like the animals living today, whereas Pleistocene fossils are much like living animals but with some differences. Many observations show that Pleistocene time was characterized by long periods of arctic conditions that allowed ice and snow to cover vast areas of land and sea, and so it is sometimes called the Ice Age. Animals of that time, such as the mammoth and the saber-toothed cat, were equipped to deal with those conditions. Holocene time is the warmer epoch since the last time of widespread icy conditions.

In the 20th century, following the discovery of radioactivity, geologists developed a tool to assign numeric ages to the divisions of geologic time. By observing the rate of decay of radioactive elements, and then measuring the amounts of both the radioactive elements and their decay products in rocks and minerals, geologists can calculate a numeric age for certain rocks and deposits, including those with bits of charcoal for carbon-dating. By careful study of the relations between the fossil-bearing sedimentary rocks and the rocks that have numeric ages, geologists have calculated the ages of the divisions of geologic time. The beginning of the Holocene was about 11,500 years ago, and the beginning of the Pleistocene was about 1,806,000 years ago.

### MAP KEY

Fault that had ground rupture in an earthquake in historic time (since 1776). Dotted where concealed by water

Holocene-active fault. Dotted where concealed by overlying rocks, sediments, or water

Quaternary-active fault. Dotted where concealed by overlying rocks, sediments, or water

Number showing the approximate location where a photograph on this poster was taken

Radiometric age (years ago)

11,500

1,806 million

23 million

65 million

251 million

542 million

2.5 billion

Mammoth

Saber-toothed cat

Primitive horse (*Eohippus*)

Trilobite

Dinosaur

*Dickinsonia*

Epoch

Holocene

Pleistocene

Quaternary

Neogene

Paleogene

Palaeozoic

Proterozoic

Eon

Cenozoic

Archean

Geologists used fossils to divide geologic time. The most primitive fossils are found in the oldest rocks, the rocks of the Archean eon. Younger are the more complex but still simple fossils of the Proterozoic eon, such as *Dickinsonia*. The Paleozoic era marked the first complex organisms, such as the trilobites. The Mesozoic era was the time of dinosaurs. The Cenozoic era is the age of mammals, such as the *Eohippus* (or dawn horse) of the Paleogene period. By Quaternary time, the fossils are of animals that are almost, but not quite, like animals that are alive today, such as the mammoth and the saber-toothed cat of the Pleistocene epoch.



### Why do geologists study faults?

Active faults generate earthquakes. Geologists study them to better understand where and when future earthquakes will occur.

Geologists study faults to better understand where large earthquakes originate. The Earth's plates are constantly moving, but most faults are motionless, locked by friction, until the day when the force on the fault builds up enough to overcome the resistance. When that happens, the rocks on either side of the fault lurch into motion, releasing pent-up energy in an earthquake. Most earthquakes are so small that special instruments are needed to detect them, but a few release huge amounts of energy, causing widespread destruction. During most earthquakes, fault motion stays below the Earth's surface, but in large earthquakes, fault motion may break through to the surface, offsetting rocks and sediments, as well as anything built on the fault, as much as ten feet or more.

Earthquake shaking can cause widespread destruction, as is shown by newspaper drawings made after the 1868 earthquake on the Hayward Fault and photos taken after the 1906 earthquake on the San Andreas Fault.

Knowing the location of active faults is important so that planners and developers can avoid building houses or other structures, which would be destroyed when the fault breaks the Earth's surface, on the faults. Geologists also study the faults to find out how quickly the stress on them is building, as well as when the last large earthquake on them was and how often large earthquakes are caused by them. This information together gives them a general idea of how soon to expect the next Big One on a particular fault. The eventual goal is accurate and precise earthquake prediction, but geologists still haven't developed the tools required to do that.

Geologists also study faults because they can affect the distribution of oil, underground water, and mineral resources. Faults also can serve as conduits for volcanic eruptions. Finally, studying faults can help to better understand how both the Earth's crust and the surface landscape formed.

11 Offset fence in Marin County, 1906

During earthquakes, faults can offset the ground surface by many feet, as shown by the offset of this fence across the San Andreas Fault after the 1906 earthquake.

12 Santa Cruz County, 1906

### Do all faults cause earthquakes?

Faults with no Quaternary activity are least likely to cause an earthquake. Holocene-active faults are considered the most active.

There are literally hundreds of faults in the San Francisco Bay region alone. All faults are the result of movement in the Earth's crust, and all but the tiniest probably have generated earthquakes. However, much of that movement and most of those earthquakes occurred far in the Earth's past. Because the pattern of stress in the crust changes over geologic time, faults are formed, move, and then are abandoned. Geologists focus their studies on Quaternary-active faults, faults that have moved in Quaternary time. Faults that have not moved in the last 1.8 million years are probably abandoned, or at least they cause an earthquake so infrequently as to be less important. On the other hand, faults that have moved in Holocene time (the last 11,500 years) are considered the most active and dangerous faults.

### Sources of Fault Mapping

Compositional faults, northeastern San Francisco Bay region—J. Urrut, William Lettis & Associates

Concord Green Valley Faults—B. Bryant and C. Wills, CGS

Faults in Santa Cruz and northern Monterey County—L. Rosenberg, Terra Geosciences

Foothills Thrust System, Santa Clara and San Mateo Counties—D. Kennedy, Sanders & Associates

Hayward Fault—J.J. Lienkaemper, USGS

Northern and Peninsular segments of the San Andreas Fault—C. Prentice, USGS

Northern Calaveras Fault—K. Kelton, William Lettis & Associates

Rodgers Creek Fault—S. Hecker, USGS, and C. Randolph-Laur, Lachell Pelletier & Associates

West Napa Fault—K. Hanson, Geomatrix, and J. Wessling, William Lettis & Associates